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SCIENCE IDENTITY AND SCIENCE CAPITAL: EMPIRICAL MAPPING FROM THE PARTICIPATION IN SCIENCE AT SECONDARY SCHOOLS

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Abstract. *Science identity and science capital (SIC) are theoretical lenses to investigate and explain participation in science. However, their qualitative and sociological orientation may limit their effectiveness in promoting science participation from school science education, so some researchers suggested the importance of mapping SIC. This study empirically develops an educational SIC map after a large sample of Spanish students self-reported their science-related attitudes and experiences on a survey. Three different self-recognitions of science participation serve as the basis for statistically identifying the relevant attitudes and experiences that shape the map. The results reveal a map's core set of relevant traits that are prevalent and common across all three self-recognitions, primarily derived from science classes and interest in science topics. Additionally, there is another minoritarian subset, specific to and consistent with each self-recognition, largely associated with science images, technological topics, and digital technologies. The map's relevant traits are further linked to the theoretical dimensions of SIC. The discussion highlights the implications of the map for supporting participation in science from school science education and for advancing research in the field. Some limitations arising from the applied survey and future research directions toward SIC assessment and SIC-oriented science education are also addressed.*

Keywords: *science capital, science identity, science-related attitudes, science participation.*

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Introduction

Societies are increasingly grounded in scientific knowledge, which not only solves but also introduces new and important personal, work-related, and social challenges, such as global warming and pandemics. Various organizations (European Commission, 2004, 2012; OECD, 2016b, 2019; United Nations, 2015) have highlighted that education, particularly science and technology (S&T) education, can help to address these challenges. The concept of scientific and technological literacy for all in S&T supports individuals to achieve the personal, labour, cultural, social, participation, coexistence, and citizenship objectives, as well as fostering democratic and economic social development (National Academies of Sciences, Engineering, and Medicine, 2016).

The increasing development of S&T systems places big demands for skilled personnel that remain unmet in many S&T disciplines. Thus, the challenge of stimulating young people's aspirations to participate in S&T is now an international concern, frequently addressed in specialized research due to its impact on the sustainability of these systems. Although developing scientific vocations has always been a core goal in science education, new educational approaches are currently required to simultaneously satisfy the growing demand for personnel and the principles of educational inclusion and social justice, which are inherent in scientific literacy for all (Archer et al., 2013).

Research Problem

Some studies have introduced the constructs science identity and science capital (hereinafter SIC) as interconnected frameworks that serve as holistic lenses to explain S&T participation. These studies have also proposed some components (competence, action, recognition, literacy, media, etc.) that make sense of data on students' choice of S&T (Archer et al., 2015; Carlone & Johnson, 2007). However, SIC research may remain abstract, generic, qualitative, and not specific enough to facilitate teachers' understanding or support school interventions. For instance, this is particularly critical when the nature of science intersects with SIC (Avraamidou & Schwartz, 2021).

This study addresses this educational gap by empirically incorporating into the abstract and qualitative SIC some specific attitudes and experiences related to S&T education on the basis of the Spanish students' recognition to

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choose S&T studies and its relationship to their self-reported educational attitudes and experiences. This approach is relevant because the specific attitudes and experiences provide educational meaning to SIC components, which can facilitate the design of consistent and appropriate educational interventions on curriculum and methodology development to enhance S&T participation (Kim & Sinatra, 2018; Kim et al., 2018; Vázquez & Manassero, 2009a, 2009b).

Research Focus

The Trends in International Mathematics and Science Study (TIMSS) (Mullis et al., 2021) and the Programme for International Student Assessment (PISA) (OECD, 2019) were designed to assess students' S&T literacy with a focus on cognitive learning, though both included some affective factors in the last waves. These studies have revealed a worrying paradox: students with high TIMSS and PISA scores perceive science education as irrelevant and show little interest toward S&T studies in many countries (OECD, 2016a, 2016b). In the long term, these affective obstacles may harm the personal and social benefits linked to S&T. Thus, fostering positive attitudes toward S&T should be seen as a key objective in school education because it improves learning and other personal and social goods (Dierks et al., 2014; Fensham, 2009). The latest waves of TIMSS (Mullis et al., 2021) and PISA (OECD, 2019) report a slight increase in students' enjoyment of science. However, Spanish PISA 2015 data indicate that 15.3% of students expect to get an S&T job by the age of 30 (López Rupérez et al., 2019).

The international decline of young people's interest in S&T careers (Lyons & Quinn, 2010) is also evident among Spanish youth, as several studies have shown. Zamora (2004) reported a sustained decline of students pursuing high school S&T studies. The Spanish National Institute of Statistics found that enrolments in physical, mathematical, and chemical sciences dropped by 63% between 1999 and 2009 (Rodríguez, 2011). Furthermore, Hernández (2010) reported that first-year enrolments in experimental, technical, and health-related studies decreased by an average of 14% (from 2000 to 2008), despite health studies increasing by 20% and experimental sciences and technical careers sharply declining by 26% and 20%, respectively.

The proportion of 15-18-year-old students in Catalonia choosing S&T studies (33%) varied significantly according to gender and sociocultural status. For example, 51% of high-status boys chose S&T studies, compared to 38% of high-status girls and only 20% of low-status girls (Everis, 2012). Similarly, young people in Spain (15-24 years old) found the scientific profession less attractive (45%) than the older participants (50%), despite valuing higher the personal compensation more and being less concerned about low salaries and job instability compared to older individuals (Fundación Española para la Ciencia y la Tecnología, 2023). Though a bit paradoxical, these overall results do not appear to reflect a general lack of interest in scientific professions among young people.

The current official Spanish statistics on pre-college education provide some up-to-date conclusions. In the 2022 post-compulsory education cohort (+16 years), 45% of students chose S&T studies across high school and vocational training, with a 9% gender gap favouring boys.

Science Identity and Science Capital (SIC)

In recent years, science identity and science capital (SIC) have emerged as complementary frameworks to understand participation in science and technology. These constructs provide a holistic lens to understand why individuals (16 and older) pursue science studies, why certain groups (women, minorities, etc.) remain underrepresented, and why many young people perceive scientific careers as "not for me" (Jenkins & Nelson, 2010). When attempting to understand participation in science, students' aspirations to become scientists appear closely linked to their attitudes toward science, such as interest, enjoyment, and ability (Palmer et al., 2017), as well as to other personal factors (e.g., image, future expectations, etc.) and social variables (e.g., ethnicity, gender, and class). A large majority (75%) of 11-year-old British students reported enjoying school science activities, but only about 17% expressed a desire to pursue scientific careers (DeWitt & Archer, 2015). On the other hand, several studies (Cleaves, 2005; DeWitt et al., 2014; Osborne & Dillon, 2008; Vazquez & Manassero, 2008) have shown a gradual and steady decline in attitudes towards science as students advance through the educational system, resulting in lower attitudes when making decisions to participate or not in S&T.

Science identity facilitates analysing shifts in perspective when scientific aspirations and vocations are due to the different levels of structures (micro, meso, and macro) involved in identity development (Carlone & Johnson, 2007). These researchers defined a person's science identity as the recognition of being a person of science, both self-recognition and recognition by others. They proposed three components to science identity: competence (knowledge of scientific content and processes), action (the ability to use scientific tools and language in daily

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life), and recognition (validation of one's identity by oneself and by others). Science identity is not innate but a developing quality that requires a comprehensive analysis and practices to address the multiple, often conflicting structures, factors, and practices that shape identity.

Butterfield and Marshall's (2022) meta-analysis of 18 studies revealed that many studies did not define science identity but instead used various sociocultural concepts of identity (affinity-identity, discursive identity, culturally situated identity, and social identity). They concluded that science identity is a type of social identity; that is, an awareness of social affiliation with science and the meanings associated with that affiliation. Social psychology further defines social identity as that part of the self-concept derived from group membership. This distinguishes it from personal identity, acknowledges the multiplicity of social identities, and highlights their continuous interaction and evolution within the same individual, altering their relative importance in the self-concept (Kim & Sinatra, 2018; Manstead et al., 1995).

Barriers to the development of science identity include stereotypes, systemic issues, microaggressions, and rejection of the social group. Supports include persistence, competence, action, recognition, and role models (Butterfield & Marshall, 2022). To study the trajectories of identity development, they proposed a three-stage framework (beginner, intermediate, and full member), each characterized by constructs such as competence, action, recognition, intergroup inclusion/rejection, and conflicting social identities. Similarly, Taconis (2022) suggested three basic identities (self, professional role, and social membership), highlighting that the identity construction becomes challenging when other identities come into conflict or dissonance. This researcher proposed mapping identities through pragmatic analysis based on the integration of expertise as a central component of S&T identity.

Science capital builds on Bordieu's concepts of habit and capital, integrating several dimensions and subdimensions. These include scientific forms of cultural capital (scientific literacy, science-related attitudes and dispositions, and transferability to daily life of scientific knowledge), science-related behaviours and practices (scientific media consumption and visits to non-formal science learning environments, centres or museums), and science-related social capital (knowing science workers, parental science qualifications, talking about science, and science identity). Science capital changes depending on the context, and educators can help develop students' science capital by valuing and linking their experiences with science and its different dimensions (Archer et al., 2015). As a result, surveys of science capital are expected to explore, compare, and map its development. They also aim to inform about policy and practice, as well as help practitioners and researchers understand its influence on youth's participation in science.

Research Aim and Research Questions

This study incorporates previous proposals to map SIC and undertakes the search for its specific elements. Social psychology serves as the basic theoretical framework (Manstead et al., 1995): science identity is a special case of social identity and follows the patterns of development and interaction outlined in this framework (Butterfield & Marshall, 2022; Kim & Sinatra, 2018; Taconis, 2022). The science capital dimensions (Archer et al., 2015) and science identity components (Carlone & Johnson, 2007) are treated as hypothetical structures. This study seeks to map and validate by empirically identifying their specific elements.

The SIC map is developed within the framework of the Relevance of Science Education Second (RoseS) research project. RoseS is an exploratory study of students' experiences with school science education based on a self-report questionnaire (RoseS-Q) and the procedures described below. The RoseS project began in 2020 and spanned multiple countries. An international group of experts developed the RoseS-Q and its framework independently of the SIC theoretical frameworks (Jidesjö et al., 2020).

Beyond the mapping aim, RoseS provides data on science participation that enable connections between participation and science education. The rationale for mapping the SIC components from RoseS data is as follows: The ultimate and shared goal of science identity and science capital is to explain S&T participation. Thus, the RoseS variables reveal significant differences between acceptance and rejection of S&T participation that have been helpful to find the elements of the SIC map. Then, the examination of the map's elements may allow assigning them to the SIC component that aligns their content, thereby creating a set of science education variables that constitute a valid and concrete map of each SIC component.

To guide this study, the following research questions are presented:

RQ1: What are the rates associated with students' S&T affiliation self-recognition?
RQ2: What educational variables show relevant differences between the acceptance/rejection groups of S&T affiliation self-recognition?

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RQ3: How do these relevant variables map onto and align with the theoretical dimensions/components of SIC?

Research Methodology

General Background

The methodology develops the intersection between SIC research and the RoseS project. The latter has contributed with the data-gathering survey, which has been applied to a large and convenience sample of Spanish secondary students. The quantitative and the qualitative analysis of the large number of variables on students' participation in science, science-related attitudes, and experiences in science education have led to finding the concrete and educational elements of the SIC map.

Participants

The RoseS target population consists of students at the end of their compulsory education (grades 9 and 10, age 15), as they reflect on their education, on what and how they have learned about S&T, and on the important decisions regarding further studies. The original database (2275 records), after quality control and refinement, resulted in a valid sample of 1909 students (49.4% identified as girls, 46.9% as boys, 4.3% did not state their gender, and 213 records were missing). Nearly all the students (97.2%) were between 14 and 16 years old (average age 15.1 years), attended 23 Spanish schools (14 public and 9 private) and none of the participants (institutions, teachers, and students) received any incentives for participating in this study. The responses were collected between 2020 and 2023.

The approval of the RoseS project by the Spanish Research State Agency required a commitment to adhere to ethical principles and comply with relevant national, EU, and international legislation on human Rights. Further, the RoseS-Q presentation informed respondents about the response anonymity, the freedom to leave items blank, the voluntary participation, and that answering implied informed consent. The separation between questionnaire administrators (school teachers) and researchers (who had no contact with respondents) further ensured anonymity. The custody of data by the university (institutional data protector) fully guarantees the respondents' fundamental rights.

Instrument and Procedures

Jidesjö et al. (2020) justified the development of the RoseS-Q based on the statistical and validation analysis of a previous version (Sjøberg & Schreiner, 2019) and a piloting of the new version in four countries. RoseS-Q is made of 167 Likert-type items considered key for the relevance of science education and grouped by thematic affinity into seven categories (Table 1). The items are written as direct, clear, simple, and short phrases (eight words on average), mostly with an affirmative and positive style. However, some items are negatively worded to counteract the acquiescence bias (Table 3 displays some items). The response format is a 4-point Likert scale (1-2-3-4), where most categories ask for disagreement/agreement, while some focus on interest or importance.

Table 1
Description of the RoseS-Q Questionnaire and Details of its Seven Categories

Categories	Label	Number of items	Item Content	Question	Measurement scale (1–4)	Latent Factors	Ordinal Alpha
What I want to learn about	A, C, E	78	S&T Topics	How interested are you in learning about...?	Not interested 1-Very interested 4	-	-
My future job	B	23	Work Traits	How important are the following traits…?	Not important 1 - Very important 4	2	.837 .804
Me and the environmental challenges	D	13	Environmental attitudes	To what extent do you agree with…?	Disagreement 1 – Agreement 4	1	.776

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Categories	Label	Number of items	Item Content	Question	Measurement scale (1–4)	Latent Factors	Ordinal Alpha
My science classes	F	10	Features of school science	To what extent do you agree with…?	Disagreement 1 – Agreement 4	1	.903
My opinions about science and technology (S&T)	G	13	Social aspects of S&T	To what extent do you agree with…?	Disagreement 1 – Agreement 4	2	.857 .811
My experiences of social and digital media	H	16	Social and digital tools for learning	How much do I use…? To what extent do you agree with…?	Usage Time Disagreement 1 – Agreement 4	1	.845
My informal science experiences	I	14	Impact on learning	To what extent do you agree with…?	Disagreement 1 – Agreement 4	2	.876 .859

Note. Ordinal Alpha for latent factor was obtained from confirmatory factor analysis of six scales (B, D, F, G, H, I). A, C, and E scales display quite diverse S&T topics, and factor analysis has been omitted.

Three RoseS-Q items assess different forms of self-recognition in S&T affiliation (hereinafter STAS-R), which serve as the independent variables of this study: becoming a scientist, getting a job in technology, and choosing an S&T subject next year. The latter item (choice of an S&T subject) includes three nominal options (science, another subject, and it depends), which align with the three categories (unequivocal, unthinkable, and insecure) described by DeWitt, Osborne et al. (2013). The responses to the first two items (become a scientist, get a job in technology) assess agreement levels on a 4-point Likert format (Disagreement 1–4 Agreement). The remaining 167 RoseS-Q items constitute the dependent variables (Tables 2 and 3 below).

The online RoseS-Q presented the items alphabetically ordered by their category labels (Table 1) and was administered by teachers to their student groups as a class assignment, following the same protocol across all participating schools. Respondents were informed their participation was anonymous and voluntary and that they could leave items unanswered (thus, some items may have different numbers of valid responses).

Data Analysis

The database was carefully refined to remove invalid answers according to various criteria (null data, homogeneous or inconsistent responses, etc.), ensuring data quality and reducing the likelihood of introducing 'noise' into the analyses. Confirmatory factor analysis identified a nine-factor latent structure for the six scales (B, D, F, G, H, I) of RoseS-Q, with high internal consistency (ordinal Omega index .882) and good factor reliability (Table 1).

A mixed quantitative and qualitative approach was employed to analyse the students' responses. Quantitative parameters were developed and qualitatively interpreted to identify the relevance of variables concerning the study's research questions. The proportion of responses at each Likert scale point quantified response percentages and allowed for the computation of item weighted averages. The distribution of variables did not meet the assumptions of normality and homogeneity of variances. Therefore, non-parametric tests (Mann-Whitney test and Cohen's r and biserial correlation of ranges) were used to calculate significance probabilities and the effect-size (ES) statistics for group differences. Comparisons between the acceptance and rejection groups derived from the three STAS-R independent variables, were performed for the 167 dependent variables (RoseS-Q items). The relevant items for the SIC map were identified based on the following interpretation of cut-off points: small (r < .20), medium (r < .40), large (r > .40).

Research Results

The results are presented below following the successive examination of the three research questions.

Independent Variables of S&T Affiliation Self-Recognition

To address RQ1, we first examined the three independent variables related to S&T affiliation self-recognition (STAS-R) (become a scientist, get a job in technology, choose an S&T subject). They connect the RoseS database with

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the SIC core, describing slightly diverse students' intentions or decisions to participate in science and displaying diverse response formats. The distribution of responses across the three STAS-Rs is presented in Table 2.

Table 2

Distribution of Responses Across the Three Independent Variables of S&T Affiliation Self-Recognition (STAS-R)

Answers	*n*	%	Valid %	Cumulated %	Collapsed %
STAS-R item: **I would like to become a scientist**					
1 Disagreement	775	40.6	47.9	47.9	68.3*
2	330	17.3	20.4	68.3	
3	310	16.2	19.1	87.4	
4 Agreement	204	10.7	12.6	100.0	31.7**
Total	1619	84.8	100.0		
Missing	290	15.2			
STAS-R item: **I would like to get a job in technology**					
1 Disagreement	650	34.0	40.0	40.0	62.6*
2	368	19.3	22.6	62.6	
3	352	18.4	21.7	84.3	
4 Agreement	255	13.4	15.7	100.0	37.4**
Total	1625	85.1	100.0		
Missing	284	14.9			
STAS-R item: **If next year you have to choose to study between a science or technology subject and a different subject, what would you decide?**					
Science	594	31.1	35.0	35.0	
Another	334	17.5	19.7	54.7	
It depends	768	40.2	45.3	100.0	
Total	1696	88.8	100.0		
Missing	213	11.2			

*Collapsed percent of answers choosing either of the two points of disagreement (1 or 2).
**Collapsed percent of answers choosing either of the two points of agreement (3 or 4).

The independent variable 'I would like to become a scientist' (hereinafter "become a scientist") has a majority response rate at the two points of disagreement (68.3%), with the highest point of disagreement (1) accounting for nearly half of all responses (Table 2). The weighted average is below 2 (M = 2.0; SD = 1.1).

Similarly, the independent variable 'I would like to get a job in technology' (hereinafter "job technology") has a majority response rate of disagreement (62.6%), with the highest level of disagreement (1) accounting for 40% of the responses (Table 2). Its weighted average is slightly above 2 (M = 2.1; SD = 1.1).

Finally, the variable "Choose to study between a science or technology subject and a different subject" (hereinafter "choose an S&T subject") shows a majority of undecided responses ("it depends" 45.3%). Slightly over one-third (35.0%) choose the S&T subject, while one-fifth choose a different subject (19.7%).

Overall, the results of STAS-R variables show that the proportion of secondary school students willing to pursue S&T studies ranges from 31% to 38%. This suggests that the rate slightly depends on the variable's content (the question asked)—whether it is scientifically oriented (becoming a scientist or choosing a S&T subject) or technologically job-oriented (getting a job in technology).

Analysis of the Dependent Variables

This section addresses the RQ2 through the statistical analysis that compares the 167 dependent variables (RoseS-Q items) between the acceptance and rejection groups drawn from the STAS-R variables. The distributions

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of these variables did not meet the normality and homogeneity of variances criteria. As a result, the Mann-Whitney non-parametric test was used to calculate statistical significance along with the effect size of the differences (Cohen's r) to compare the groups of the independent STAS-R variables. The results of these comparisons constitute the key findings for answering the research questions related for empirically mapping and validating the theoretical SIC.

The answers to the third independent variable ("choose an S&T subject") generated three groups (science, another, depends). The non-parametric Kruskal-Wallis test and the ES statistic (epsilon-squared) were applied to identify items with relevant global differences, as well as pair comparisons. The latter showed that the differences between the "depends" group and the other two groups were small: the differences between the "depends" group and the "another" group were nonsignificant ($p > .05$) for most dependent variables and not relevant for any of them (small ES); the differences between "depends" and "science" groups were nonsignificant ($p > .05$) in many variables, and the few relevant displayed small ES. Accordingly, the subsequent analysis focused on the differences between the two groups with firm affiliation: the group that chose "science" and the group that chose "another". Comparisons between these two groups were performed using the Mann-Whitney and Cohen *r* tests because only two groups were involved (table 3).

Table 3

Roses-Q Items That Attain Relevant Effect Size of the Differences (r > .20) Between the Two Groups of the Three Independent STAS-R Variables and Their Assignations to the Dimensions of Science Capital and Science Identity

Specific RoseS-Q items (category label and name, number and statement)	Cohen r (> .20)*			Dimensions**	
	Become a scientist[o]	Job in technology[o]	Choose S&T subject[a]	Science Capital	Science Identity
ATopics_01 Chemicals, their properties and how they react	.30	.21	.37	SL	COMP
ATopics_09 Atoms and molecules	.34	.22	.39	SL	COMP
ATopics_13 Black holes, supernovas and other spectacular objects in outer space			.21	SL	COMP
ATopics_21 Explosive chemicals	.20	.21	.21	SL	COMP
ATopics_22 Biological and chemical weapons and what they do to the human body			.25	TR	ACT
ATopics_33 Rockets, satellites and space travel		.24	.22	SL	COMP
ATopics_34 How X-rays, ultrasound, etc. are used in medicine	.26		.3	TR	ACT
ATopics_35 How a nuclear power plant functions	.21	.25	.26	TR	ACT
BJob_04 Working with machines or tools		.30		TR	ACT
BJob_07 Making, designing or inventing something		.25		TR	ACT
CTopics_01 How a cell phone works		.26		TR	ACT
CTopics_11 How emissions of carbon dioxide can affect the climate	.22		.23	TR	ACT
DEnvironment_03 Science and technology can solve all environmental problems		.20		AT	COMP
ETopics_02 The greenhouse effect and how it may be changed by humans	.21			TR	ACT
ETopics_04 How technology helps us to handle waste, garbage and sewage	.21	.30	.22	TR	ACT
ETopics_16 Renewable sources of energy from the sun and the wind etc.		.23		SL	COMP
ETopics_25 Benefits and possible hazards of gene modification (GMO) in farming	.23	.22	.2	TR	ACT
ETopics_27 Why scientists sometimes disagree	.28	.22		SL	COMP
ETopics_28 Famous scientists and their lives	.29			PER	ACT

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Specific RoseS-Q items (category label and name, number and statement)	Cohen r (> .20)*			Dimensions**	
	Become a scientist°	Job in technology°	Choose S&T subject[a]	Science Capital	Science Identity
ETopics_29 Big blunders and mistakes in research and inventions	.27	.26	.22	PER	ACT
ETopics_30 Inventions and discoveries that have changed the world	.23	.21	.24	PER	ACT
ETopics_31 Very recent inventions and discoveries in science and technology	.28	.31	.28	PER	ACT
ETopics_32 Phenomena that scientists still cannot explain			.22	SL	COMP
FClasses_01 School science is a difficult subject			.25	AT	COMP
FClasses_02 School science is interesting	.38	.22	.47	AT	COMP
FClasses_03 School science has opened my eyes to new and exciting jobs	.43	.24	.42	TR	ACT
FClasses_04 I like school science better than most other subjects	.53	.29	.56	AT	COMP
FClasses_05 The things that I learn in science at school will be helpful in my everyday life	.38	.22	.34	TR	ACT
FClasses_06 School science has made me more critical and sceptical	.38	.25	.32	TR	ACT
FClasses_07 School science has increased my curiosity about things we cannot yet explain	.37	.22	.35	TR	ACT
FClasses_08 School science has shown me the importance of science for our way of living	.37	.23	.34	TR	ACT
FClasses_09 School science has taught me how to take better care of my health	.24		.22	TR	ACT
FClasses_12 School science has helped me to understand sustainability solutions in my everyday life	.34	.27	.28	TR	ACT
GS&T_01 Science and technology are important for society			.24	AT	COMP
GS&T_03 Thanks to science and technology, there will be greater opportunities for future generations			.21	TR	ACT
GS&T_06 Science and technology will help to eradicate poverty and famine in the world	.24	.22		TR	ACT
GS&T_07 Science and technology can solve nearly all problems	.25	.24	.24	AT	COMP
GS&T_08 Science and technology are helping the poor	.23	.23		TR	ACT
GS&T_12 We should always trust what scientists have to say	.26	.24		SL	COMP
HUse_02 Online resources (e.g., NASA, CERN…)	.21			MED	ACT
HUse_06 Computer games		.20		MED	ACT
HUse_07 Programming and coding		.24		MED	ACT
HUse_08 Digital fabrication tools (e.g., 3D-printers & Laser cut)		.20		MED	ACT
HUse_09 Microcontrollers (e.g., Arduino, Mindstorms…)		.20		MED	ACT
IExperiences_03 Visit a science centre			.22	NFA	ACT
IExperiences_11 Play computer games		.21		MED	ACT

° Two groups compared: the group of *Agree* responses (collapsing answers 3 and 4 of the Likert format) and the group of *Disagree* responses (collapsing responses 1 and 2 of the Likert format).
[a] Two groups compared: the group that chooses the S&T subject and the group that chooses another subject.
* r: Cohen biserial correlation.
** Dimensions of human capital: scientific literacy (SL); attitudes related to science (AT); transferability (TR); media consumption (MED); knowledge of scientific persons (PER); non-formal activities (NFA). Components of science identity: competence (COMP); action (ACT)

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Table 3 shows the RoseS items that reached relevant differences ($r > .20$) in the comparisons between two groups of the STAS-R variables ("become a scientist," "job technology," and "choose an S&T subject"). The latter focuses on comparing the two groups with firm self-recognition: "science" and "another."

The overall comparisons between the two collapsed agreement and disagreement groups of the independent variable "become a scientist" revealed that 115 RoseS-Q variables showed statistically significant differences ($p < .01$), and that 28 variables exceeded the ES threshold ($r > .20$). However, only one variable (FClasses_04 I like science better than most other school subjects) achieved a large ES ($r > .50$).

Comparisons between the two collapsed groups of agreement and disagreement with the independent variable "job technology" showed that 128 RoseS-Q variables achieved a statistically significant difference ($p < .01$) between these two groups, and 33 of them exceeded the threshold ($r > .20$) of the ES. However, none of these variables reached a very large ES ($r > .50$).

Comparisons between the two "choose an S&T subject" groups indicated that 85 RoseS-Q variables reached a statistically significant difference ($p < .01$) between these two groups, and 29 of them exceeded the ES threshold ($r > .20$), although only one (I like science better than most other school subjects) reached a large ES ($r > .50$).

Analysis of the Relevant Empirical Traits for Each Independent Variable

The analysis of empirical traits reveals quantitative consistency in the results for mapping SIC. Approximately 100 traits (dependent variables) showed significant differences ($p < .01$) between the two acceptance and rejection groups of the three independent STAS-R variables, and this set is mostly identical across the three STAS-R. Similarly, the number of traits (28, 33, and 29, as shown in Table 3) reaching a relevant ES ($r > .20$) for the three STAS-R variables are also remarkably similar and consistent with each other (Table 3).

The independent variable, "become a scientist," presents 28 traits that empirically show relevant differences (r > .20) between the acceptance and rejection groups (Table 3). Half of these SIC-relevant features refer to curricular topics (14), with the largest differential interest observed in atoms and molecules, chemical products, and applications in medicine. Almost all the items of the school science class category (9 out of 10) are also relevant features, where the following three achieve the largest differences: I like science more than other subjects; Science classes have made me more critical and sceptical; Science has opened my eyes to new and exciting jobs. The remaining relevant traits of this first variable show the smallest differences and correspond to the S&T image category (e.g., S&T will help eradicate poverty and hunger in the world) and the frequency of digital media usage in science classes.

The "job technology" independent variable displays 33 traits with relevant differences ($r > .20$) between the acceptance and rejection groups (Table 3). Over one-third of these relevant features of SIC (13) refer to curricular topics, with the largest differential interest observed in topics on modern inventions and discoveries and technology as an aid to waste, garbage, and wastewater management. The fourth part of the relevant features consists of almost all the items related to school science classes (8 out of 10), among which the following stand out: Science is an interesting school subject; Science has opened my eyes to new and exciting jobs; I like science more than other subjects. In addition, four traits related to the S&T image (S&T can solve almost every problem; We should trust what scientists say), and four traits of frequency of digital media use in science classes (focused on programming and coding) also contribute to this technological aspect of SIC. The rest of the traits that complete this technological identity contain two items about a future job (Working with machines and tools; Making, designing, or inventing something), one item of environmental attitudes (S&T can solve all environmental problems), and another item of extracurricular experiences (Digital games to learn science).

The "choose an S&T subject" independent variable displays 29 features with empirically relevant differences ($r > .20$) between students who choose the S&T subject and those who choose another subject (Table 3). Half of these relevant SIC features refer to curricular topics (15), with the greatest differential interest observed in topics on atoms and molecules, chemical products, and applications in medicine. The other half of the relevant features consist of all the items of the school science classes (10), among which the following stand out: I like science more than other subjects; Science is an interesting subject; Science has opened my eyes to new and exciting jobs; Science made me more critical and sceptical. The remaining four traits correspond to three traits of the S&T image, highlighting that S&T is important to society and can solve almost all problems, and, finally, the effectiveness of learning science from visits to a science centre.

Further, these results not only provide the empirically relevant SIC traits based on the STAS-R variables (become a scientist, job in technology, choose an S&T subject) but also highlight mutual consistency. Firstly, the relevant SIC traits in the first (become a scientist) and third variables (choose an S&T subject) are practically identical to

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each other, with 75% of the traits being common to these two independent variables. Secondly, another aspect of consistency in the SIC profiles is that the relevant traits obtained in the second variable (job in technology) differ from the SIC traits generated by the other two variables in ten traits. These ten traits are exclusive of "job in technology" and are not relevant for the other two variables. In addition, the consistency is reinforced by the fact that the contents of these ten traits consistently correspond to technological topics (problem-solving, digital media, inventions, machines, designing, inventing, etc.).

Thirdly, the items with the largest ES in the differences, indicative of greater statistical power to differentiate between STAS-R acceptance and rejection, also show consistency across the three STAS-R variables. For instance, the item with the largest ES (I like science more than most other school subjects) is the same for "become a scientist" ($r = .56$) and "choose an S&T subject" ($r = .53$). Further, its content (liking science subjects) is obviously required (consistent) to become a scientist and choose an S&T subject. Similarly, the largest ES on "job in technology" ($r = 0.31$) is associated with the interest in modern inventions and discoveries in S&T, which is also consistent with the technological content of getting a job in technology.

Fourth, the differences between the three SIC profiles are quantitative and qualitative (Table 3). The quantitative difference refers to the magnitude of the ES of the differences between profiles. The SIC profiles of the variables "become a scientist" and "choose an S&T subject" present 10 items with medium to high ES ($.30 < r < .54$). However, the SIC profile of the variable "job technology" is lower, as its largest ES (modern inventions and discoveries in S&T) is hardly moderate ($r = .31$).

The main qualitative difference between the three SIC profiles, empirically generated from the STAS-R, lies in the content of the items with the highest ES differences in each profile. On the one hand, the SIC profiles in the variables "become a scientist" and "choose an S&T subject" are practically identical in their 10 most relevant items. The common core consists of seven items from science classes and two topics (chemicals and atoms and molecules), and the difference comes down to a single trait (understanding sustainable solutions in my everyday life, for the SIC in "become a scientist," and applications in medicine in "choose an S&T subject"). On the other hand, the single trait of the SIC profile for "job technology" with the highest ES (modern inventions and discoveries in S&T) has nothing to do with the previously mentioned traits.

This set of relevant traits defines the students' SIC regarding the groups accepting/rejecting the S&T affiliation along the three STAS-R variables (become a scientist, job in technology, and choose an S&T subject), which is the key feature of SIC. Thus, the traits that generate the relevant differences in S&T affiliation specify the SIC map (Table 3). Overall, the SIC map comprises 46 different traits: 18 are common to the three STAS-R variables, 8 are shared by two variables, and the remaining 20 appear in only one variable. This specification of the SIC is robust because the traits are supported by a stringent criterion ($r > .20$; $p < .00000001$) for identifying the differences between students who express acceptance and those who express rejection.

Analysis of the Traits of the Map and the Dimensions of Science Identity and Capital

This section addresses the RQ3 by qualitatively analysing the consolidated traits for the SIC map in relation to the SIC theoretical dimensions and components. The 18 traits shared by the three STAS-R variables form the core of the SIC map because they are common to all three variables and further represent most traits (between 64% and 55%) within each variable. Further, this commonality of the SIC core is independent of the variable or question used to define students' affiliation with S&T, and this independence represents a significant finding.

The SIC core composition consists of nine S&T topics, eight items related to science classes, and a single trait of the S&T image (S&T can solve almost all problems). Considering the content of each item and the dimensions of science capital, two elements of the SIC core may correspond to scientific literacy (SL), three to science-related attitudes, 10 to transferability, and three to knowing scientific persons. From the perspective of the science identity components, five traits belong to competence and 13 to action.

In regard of the relevant traits shared by two of the STAS-R variables (8), almost all (7) are generated by "become a scientist" and are shared with "job in technology" (4) and "choose an S&T subject" (3). Considering the SIC dimensions, these traits spread on scientific literacy and transferability and on competence and action.

Another finding reveals that the traits that are relevant only in one variable (20) mostly belong to "job in technology" (9) and "choose an S&T subject" (8), whereas only three traits belong to "become a scientist." The nine traits that are only relevant in the specific profile of "job in technology" highlight again the consistency between variables and relevant traits, as they all emphasize technological aspects. These traits fall into the categories of digital technology use (5), features of future job (using machines and designing and inventing), and technologi-

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cal topics (cell phones and renewable energies). Considering the dimensions of SIC, these traits mainly spread on transferability and action components.

On the other hand, the eight traits that are only relevant in the specific profile of "choose an S&T subject" correspond to the image of S&T (2), interest in spectacular space topics, unexplained phenomena, and biological and chemical weapons. Further, this is the unique profile that includes a non-formal experience (visiting a science centre) and the perceived difficulty of learning science. Once again, it appears consistent that the subject difficulty, spectacular content, and the importance of science for future opportunities may lead to differences when choosing an S&T subject.

In summary, the SIC map identifies most core traits that are independent of the type of STAS-R requested, along with another set of traits that are specific to each variable. The technological items generated by "job in technology" stand out for their coherence with technology-related issues and further support the map's consistency. The traits of the SIC map spread across all the dimensions of science capital and the components of science identity.

Discussion

Science identity and science capital (SIC) have been proposed and researched as explanatory lenses of S&T affiliation within a sociocultural framework, which emphasizes analyses focused on the intersectionality of socially important variables, such as gender, ethnicity, or social class (Archer et al., 2015, 2023; Carlone & Johnson, 2007; DeWitt, Archer et al., 2013).

As the qualitative and sociocultural status of SIC remains somewhat distant from school science education, some researchers have suggested a more concrete mapping of SIC (Butterfield & Marshall, 2022; Taconis, 2022). Thus, this study contributes a SIC map that is derived from a survey with a science education approach and is independent of mainstream qualitative and sociocultural SIC research (DeWitt & Archer, 2015; Moote et al., 2021).

The common key point of SIC research is the S&T affiliation or membership (acceptance or rejection), which is the third component of science identity (Carlone & Johnson, 2007) and the explanatory aim of science capital (Archer et al., 2015). Accordingly, this study operationalizes affiliation through STAS-R items of the survey ("become a scientist," "get a job in technology," and "choose an S&T subject"), thereby broadening the scope of the map. The overall answer to the first research question (RQ1) indicates that students' S&T engagement ranges from 31% to 38%, which is higher than the percentages reported by López et al. (2019).

The comparison between the acceptance/rejection groups generated by the STAS-R variables enables the identification of the specific traits that constitute SIC and establishes their relationships to the theoretical dimensions proposed for SIC (Archer et al., 2015; Carlone & Johnson, 2007). A rigorous criterion (Cohen's $r > .20$) provides the basis for answering the second research question (RQ2) by identifying a 46-trait set that operationalizes the SIC map and offers a measure of the trait relevance.

The map includes an 18-trait subset, common and predominant across all three STAS-R variables, and a 28-trait subset, which is not shared by all three STAS-R variables. The former constitutes the key core of the SIC map, as it is independent of the type of recognition (become a scientist, job in technology, or subject choice) that generated it. The latter shows internal consistency with respect to its generative variable and discrimination in relation to the other variables, providing additional support and sensitivity to the SIC map (Butterfield & Marshall, 2022; Kim et al., 2018). In summary, this map contributes educationally relevant information, and its relationship to SIC dimensions supports its empirical validation, which may help advance the research field (Archer et al., 2023).

Finally, the assignment of the relevant traits of the SIC map to the theoretical dimensions of SIC addresses the third research question (Rq3) and completes the proposal. The map traits are structured across the dimensions of science capital: scientific literacy (9 traits), attitudes related to science (6 traits), transferability (20), media consumption (6), knowing scientists (4), and non-formal activities (1) (Archer et al., 2015). Regarding science identity, 15 map traits correspond to the competence dimension and 31 to the action dimension (Carlone & Johnson, 2007). Overall, the empirical SIC map contributes to reinforcing the role of SIC as the lens for exploring the participation in S&T by embodying SIC through specific traits that are useful not only for SIC research but also for science education and science teachers.

Conclusions and Implications

This study contributes new, relevant, and specific traits that map the dimensions of science capital and the components of science identity, adding to SIC some educational value for science education and science teachers.

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For instance, scientific literacy is operationalized through interest in scientific knowledge (e.g., atoms and molecules), knowledge about science (e.g., scientists sometimes disagree), and citizen knowledge (e.g., renewable sources of energy). Similarly, attitudes toward science (e.g., school science is interesting), transferability (e.g., greenhouse effect and how it may be changed by humans), media consumption (e.g., online resources), knowledge of scientific persons (e.g., famous scientists and their lives), non-formal activities (e.g., visit a science centre) are operationalized by a set of specific educational traits. Another similar novelty is the specific map of science identity dimensions, such as competence (e.g., science and technology are important for society) and action (e.g., school science has helped me to understand sustainability solutions in my everyday life).

The main consequence for research and educational practice is that the set of relevant traits can be used to teach and assess the individuals' SIC at a particular time point as well as to analyse SIC trajectories over time. Furthermore, it is worth noting that the categories of interest in science topics and the science classes dominate the relevant SIC traits, each suggesting direct implications for school science education and teachers. Overall, teachers should focus on improving students' SIC traits by developing them within the classroom to make them more engaging and effective, especially for less engaged students. For instance, the trait "School science has opened my eyes to new and exciting jobs" achieved the highest relevance; thus, teachers should focus on prioritizing the job-oriented aspects of science learning. In addition, the findings point out that the instrument could be reduced to the 46 relevant SIC items, making it more manageable and practical for research and teaching.

The limitations of this study are mainly derived from its independent design (based on the RoseS-G instrument) in relation to mainstream sociocultural research on SIC. However, this limitation can also be considered a strength, as the independence contributes to reinforcing this validation and to complementing the sociocultural approaches. However, it is noteworthy that the RoseS-G lacks items about parental qualifications and talking about science, which restricts two SIC dimensions in the study. Another qualitative limitation relates to the scientific literacy dimension of science capital, which is here interpreted as students' interest in S&T topics (chemicals, atoms and molecules, etc.). Nonetheless, the centrality of interest for S&T learning and aspirations does diminish its importance. Finally, gender analyses of the SIC map are omitted to avoid exceeding the study's length.

The findings of this study provide valuable opportunities for further research and practical application. Science teachers should explicitly address the relevant traits of the SIC map (e.g., relevant topics, perceptions of science classes) as a pedagogy to positively enhance and develop their students' SIC. On the other hand, the reduced list of relevant traits may be used in research as a SIC assessment tool, either to capture an instant snapshot or to follow developmental trajectories. From this instrumental view, new research challenges focus on examining issues of applicability, validity, and reliability.

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Declaration of Interest

The authors declare no competing interest.

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